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Paddy Soils in Tropical Asia

Part 2. Description of Material Characteristics

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In the preceding paper[1] fertility characteristics, such as organic matter content, cation exchange capacity, exchangeable cations and available as well as total phosphorus contents, were described. In the present paper characteristics that are more directly connected with the soil material, i.e., textural composition, clay mineralogical composition, and total chemical composition, are described.

Samples and Methods

The number and description of the samples are same as before[1]. Again only the surface soil samples are taken up, for the subsurface and subsoil materials in the rooting zone of rice plant are in most cases similar to the surface soil material.

The mechanical (or textural) composition was determined either by the hydrometer or by the pipette method, taking the following international grain size (equivalent diameter) limits for different textural separates:

Coarse sand	2 –0.2 mm
Fine sand	0.2 –0.02
Silt	0.02–0.002
Clay	<0.002

The dispersion of clay was satisfactory after successive hydrogen-peroxide and hydrochloric acid treatments.

Clay mineralogical composition was semi-quantitatively assessed by measuring the areas of 7 Å, 10 Å, and 14 (to 15) Å peaks on the X-ray diffraction diagram for the oriented specimen of Ca-saturated and air-dried clay and calculating the area of each peak as the percentage of the total area of the three peaks. As chlorite seldom occurs, 7 Å minerals may be regarded as 1:1 type clay minerals of kaolin group, and 10 Å minerals as illite or clay micas. The 14 Å minerals consist mainly of montmorillonite, vermiculite, and Al-interlayered vermiculite-chlorite intergrades, of which montmorillonite is the most common clay mineral species. It tends to predominate particularly in soils containing a high amount of 14 Å minerals. Amorphous clays were not estimated. One sample from Indonesia and 3 samples from the Philippines did not contain crystalline clay minerals. The

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allophanic nature of the clay fraction of these soils has been established and reported earlier.[2]

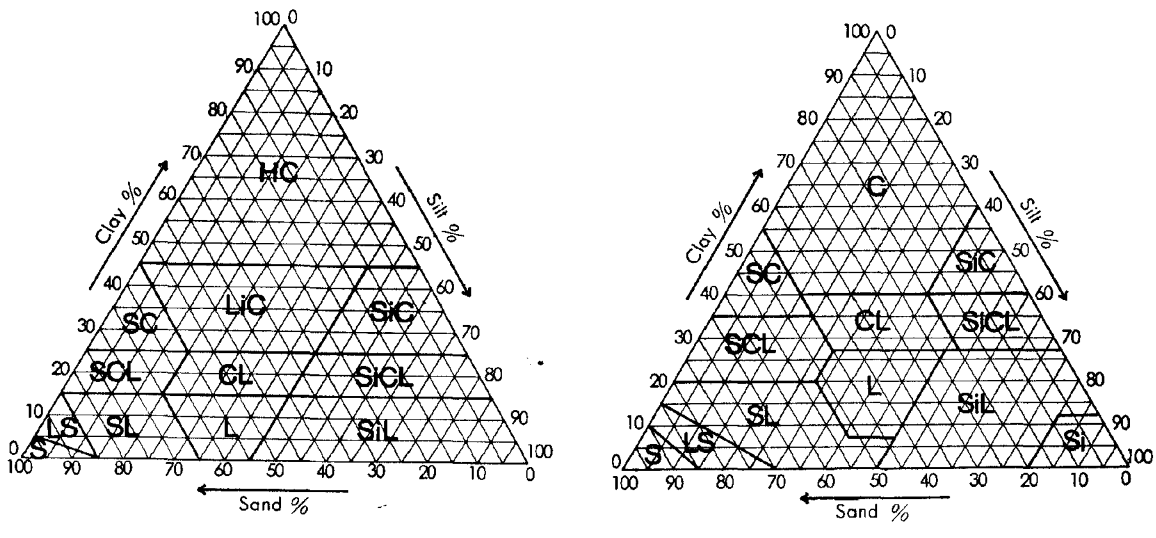
Total contents of nine major elements (Si, Fe, Al, Ca, Mg, Mn, Ti, K, P) were determined by X-ray fluorescence spectrography using the method proposed by Norrish.[3] As stated elsewhere[4], this method has fair accuracy in comparison with the chemical method and good reproducibility. The results of analyses were recalculated to make the sum of the contents of the 9 elements 100%, neglecting Na and other minor elements.

Results and Discussions

1. Textural Composition

The textural classes presently used in Japan are defined in graphic form as shown in Fig. 1 in terms of clay, silt and sand (coarse and fine sands combined). For comparison, the USDA system of textural classification[5] is also shown in Fig. 1, as it is widely used in the countries in tropical Asia. But in the latter system, as the silt fraction is between 0.05 and 0.002 mm in equivalent diameter, it is not possible to convert the Japanese classes to the USDA classes.

The textural data of the samples are plotted in the triangular diagram by countries, as shown in Fig. 2, and the distribution of the samples among different textural classes is given in Table 1. From the figure it is at once clear that Sri Lanka samples are concentrated in the lower left corner that is an area of high sand and low silt contents. The same is evident in the table, which indicates that 72.6% of the Sri Lanka samples are classified as sandy (S, LS, SL, SCL, and SC), leaving only 15.2% and 12.1% in LiC and HC classes, res-



a. Japanese system of textural classification　　b. USDA system of textural classification

Fig. 1 Triangular diagrams for textural classification: S-Sand; LS-Loamy sand; SL-Sandy loam; L-Loam; SiL-Silt loam; Si-Silt; SCL-Sandy clay loam; CL-Clay loam; SiCL-Silty clay loam; SC-Sandy clay; LiC-Light clay; SiC-Silty clay; C-Clay; HC-Heavy clay

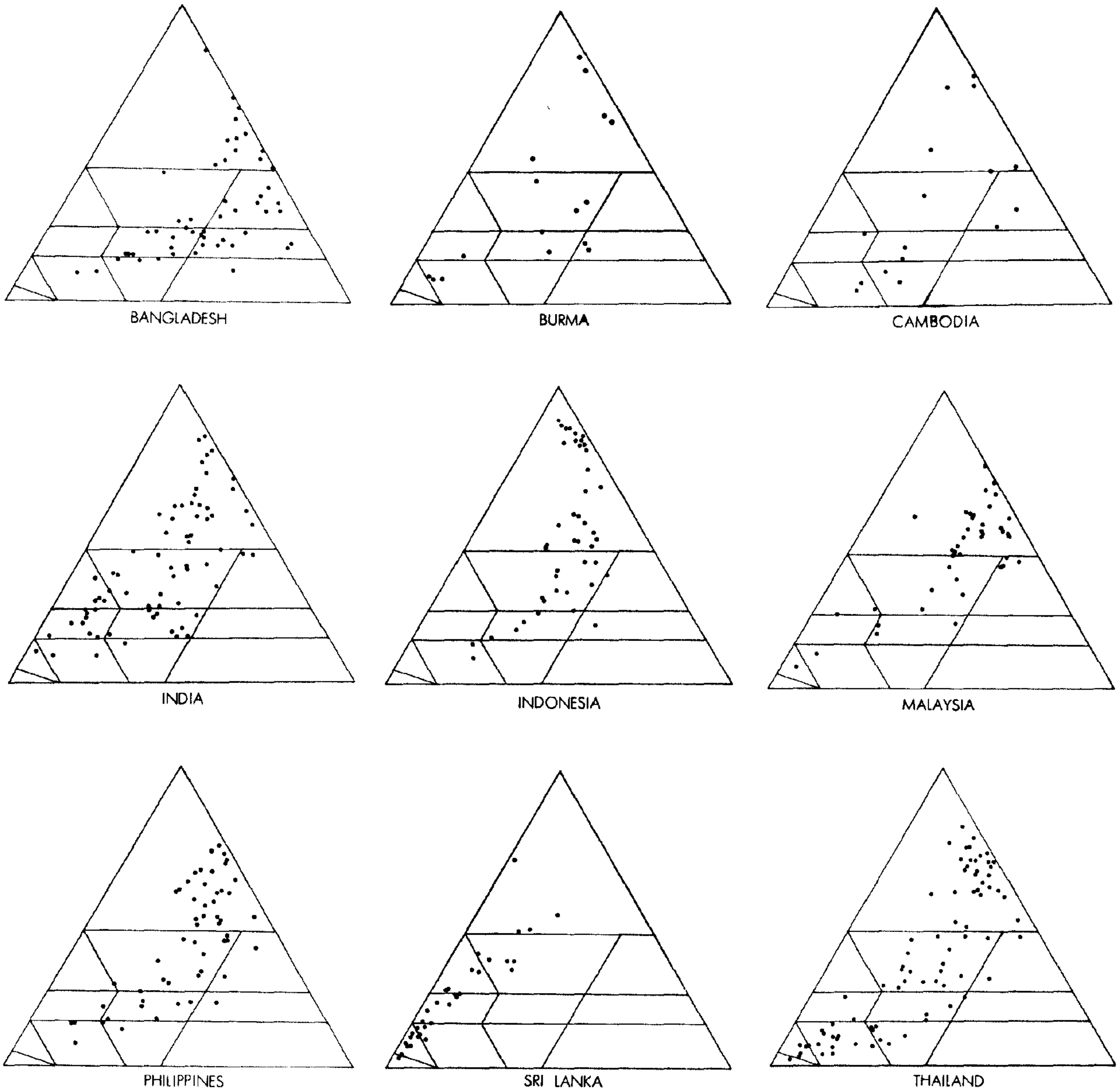


Fig. 2 Distribution of sample soils in the triangular diagram for textural classification by countries

pectively. The sandy and poor-in-silt nature of the sample soils can be explained by the fact that the greater part of paddy soils in Sri Lanka is developed on residual or local alluvial, i.e., poorly sorted, materials derived from well-weathered gneissic rocks. While coarse quartz grains are very resistant to weathering, fine quartz and other minerals of fine sand and silt size are totally lost or transformed into clay by intensive chemical weathering. As a matter of fact, not only silt but also fine sand contents are lesser than coarse sand contents in many of Sri Lanka soils.

In Fig. 2 another characteristic pattern is seen in the case of Bangladesh soils, which are

Table 1 Percentage Distribution of Sample Soils among Different Textural Classes

Textural Class	S	LS	SL	L	SiL	SCL	CL	SiCL	SC	LiC	SiC	HC
Bangladesh	0	0	3.8	5.7	1.9	0	19.8	19.8	0	7.5	17.0	24.5
Burma	0	0	18.8	0	0	6.2	12.5	12.5	0	18.8	0	31.2
Cambodia	0	0	12.5	12.5	0	6.2	12.5	0	0	9.4	12.5	34.4
India	0	1.4	2.7	1.4	0	11.6	12.3	0	8.2	23.4	2.7	36.3
Indonesia	0	0	4.5	0	0	0	10.2	2.3	0	21.6	2.3	59.1
Malaysia	0	2.4	2.4	0	0	0	7.3	0	4.9	12.2	9.8	61.0
Philippines	0	0	5.6	3.7	0	1.8	12.0	1.8	0.9	22.2	3.7	48.1
Sri Lanka	3.0	21.2	13.6	0	0	21.2	0	0	13.6	15.2	0	12.1
Thailand	1.2	5.6	15.6	7.5	0	2.5	5.0	0	0	22.5	2.5	37.5
Tropical Asia	0.5	3.3	7.8	3.4	0.2	5.0	10.1	3.5	3.2	18.3	5.4	39.3

generally shifted towards lower right side of the triangle or towards silty textural classes. Table 1 indicates that about 40% of the total samples from Bangladesh fall into silty classes (SiL, SiCL, SiC). The silty nature of the materials is a feature common to both Ganges and Brahmaputra sediments.

Abundance of heavy-textured soils is noticeable in the case of Indonesia, Philippines, and Malaysia, of which the former two are from the volcanic regions of Insular Southeast Asia. The basic nature of volcanic ejecta is the cause of the heavy texture, because they are readily weathered to clay without leaving sand-size grains behind. Many of the rice areas in Malaysia are reclaimed from marine and fresh-water swamps which are rich not only in organic matter, as mentioned in the preceding paper, but also in clay. Thus, the heavy texture of Malayan soils is conditioned by the sedimentary process, while that of Indonesian and Philippine soils is caused by the basic nature of their parent rocks.

Among the Thai soils sandy, light-textured soils from the Northeast or Khorat Plateau region make up one cluster, as seen in the lower left corner of the triangle. Another large cluster of samples seen in the upper right corner is mainly made of the soils from the Bangkok Plain.

The heavy-textured soils from India are mostly grumusols and grumusolic alluvial soils in deltas of such big rivers as the Ganges, Godavari-Krishna, and Cauvery. Many of the sandy clay and sandy clay loam soils are on strongly weathered old alluvial terraces or lateritic plateaus.

Cambodian and Burmese soils are rather scattered in the triangular diagrams. No general remarks may be made on the basis of such a small number of samples.

The mean and standard deviation of the contents of clay, silt and sand are tabulated in Table 2 by countries. When plotted in the triangular diagram, the points representing the mean compositions of Burma, Cambodia, India, and Thailand are clustered in the center, with those of Indonesia, Malaysia and the Philippines shifted somewhat towards upper right, that of Bangladesh slightly towards lower right, and the one for Sri Lanka greatly towards lower left, making what is stated above still clearer.

For comparison, the mean textural composition for 155 Japanese paddy soils sampled

Table 2 Means and Standard Deviations for Sand, Silt, and Clay Contents by Countries (in %)

Country	No. of Samples	Sand		Silt		Clay	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
Bangladesh	53	25.6	20.0	42.8	13.1	31.6	17.2
Burma	16	38.2	28.4	26.0	14.2	35.7	25.2
Cambodia	16	33.9	25.5	31.4	12.7	34.7	24.3
India	73	36.4	22.8	24.3	11.2	39.3	19.6
Indonesia	44	22.5	18.3	26.3	10.8	51.2	24.2
Malaysia	41	22.5	22.0	31.3	10.6	46.1	16.1
Philippines	54	27.1	20.8	30.8	9.2	42.1	18.8
Sri Lanka	33	68.3	20.2	7.6	6.0	24.1	15.8
Thailand	80	38.2	29.3	25.2	11.1	36.7	24.6
Tropical Asia	410	33.9	26.0	27.7	13.7	38.4	21.6
Japan	155	49.2	18.2	29.6	10.6	21.2	10.1

from all over the country is given in the last row of Table 2. In Japanese soils the silt content is nearly equal, the clay content is much lower, and the sand content is complementally much higher as compared to tropical Asian paddy soils. Low standard deviations for the Japanese soils imply homogeneity in texture.

2. Clay Mineral Composition

The clay mineral composition is also plotted in the triangular diagram in terms of 7, 10 and 14 Å minerals. In this paper 10 classes are set up, as shown in Fig. 3, based on relative abundance of the respective mineral species. Figure 4 shows the sample data plotted in the diagram for each country, and Table 3 gives the number of samples falling into each class.

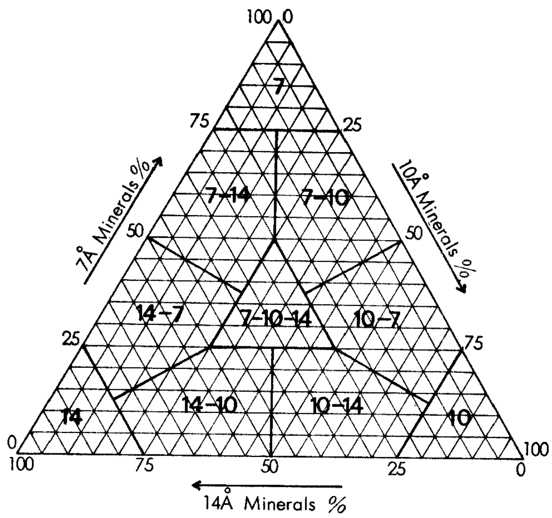


Fig. 3 Triangular diagram for grouping clay mineral compositions: 7-7 Å minerals, 10-10 Å minerals, 14-14 Å minerals

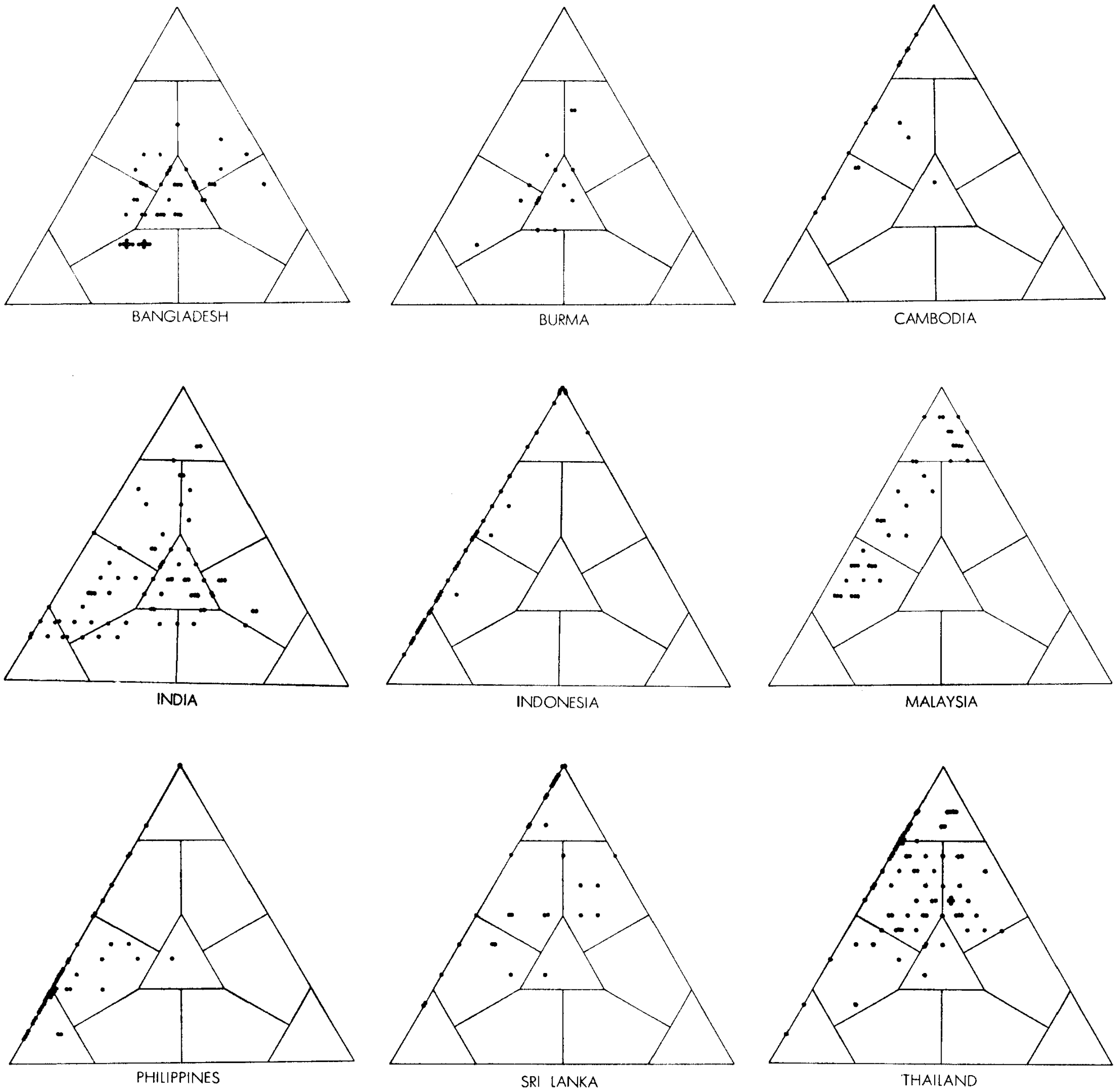


Fig. 4 Distribution of sample soils in the triangular diagram for grouping clay mineral compositions by countries.

As evident from the figures and the table, no sample contains 10 Å minerals in amounts greater than 75% of the total crystalline clays. Even samples containing 10 Å minerals as the dominant clay species, accompanied either by 7 Å (10-7) or by 14 Å minerals (10-14), are very rare.

There seem to be roughly three types of clay mineral composition, i.e.,

"7-dominant" type, having either 7, 7-10, or 7-14 combinations—Cambodia, Malaysia, Sri Lanka, and Thailand,

Table 3 Percentage Distribution of Sample Soils among Different Clay Mineralogical Groups

Clay Mineral Group	7	7-10	7-14	10	10-7	10-14	14	14-7	14-10	7-10-14
Bangladesh	0	13.2	13.2	0	6.6	0	0	10.4	26.4	30.2
Burma	0	15.6	12.5	0	2.1	2.1	0	25.0	6.2	36.4
Cambodia	31.2	0	34.4	0	0	0	0	28.1	0	6.2
India	3.4	6.2	13.7	0	9.6	4.1	8.9	22.6	8.9	22.6
Indonesia	20.4	0	18.2	0	0	0	28.4	30.7	0	0
Malaysia	34.1	2.4	24.4	0	0	0	0	39.0	0	0
Philippines	3.7	0	9.2	0	0	0	37.0	42.6	0	1.8
Sri Lanka	39.4	16.7	18.2	0	0	0	6.1	16.7	0	3.0
Thailand	18.8	21.0	46.0	0	0.6	0	2.5	6.9	0	4.2
Tropical Asia	14.8	9.1	22.0	0	2.8	0.8	10.5	22.9	5.2	10.9

"14-dominant" tpye, having either 14, 14-7, or 14-10 combinations—Indonesia and the Philippines,

"7-10-14-even" type, having all 3 clay species each more than 25%—Bangladesh, Burma, and India.

Of the three types, "7-dominant" type may be regarded as the most highly weathered and "14-dominant" type as the least weathered, "7-10-14-even" type being transitional between the two.

Samples containing more than 75% 14 Å minerals ("14" in Fig. 3) are either grumusols or grumusolic alluvial soils derived from calcareous sediments or from basic volcanic ejecta. The "14-7" and "7-14" combinations occur most frequently among the soils developed on recent alluvial as well as deltaic sediments. Only Bangladesh soils have appreciable numbers of "14-10" combination and the soils having this clay composition are exclusively of Gangetic alluvia origin.

Soils containing more than 75% 7 Å minerals are most frequently encountered in the Wet Zone of Sri Lanka, East Coast of Malaysia, and Southern Peninsular region of Thailand. The Khorat Plateau region of Thailand and Cambodia also have many samples having this clay composition. Besides these regions, soils containing this high amount of kaolin minerals are commonly found on highly weathered middle and high terrace sediments, which often contain pisolitic concretions and/or lateritic nodules.

The Indonesian samples containing more than 75% 7 Å minerals in their clay fraction are almost exclusively latosols. They are derived from basic pyroclastic materials and seem to contain, besides kaolin minerals, high amounts of allophane and oxide minerals (goethite and gibbsite).[2]

In Table 4 the mean and the standard deviation of the contents of three clay mineral species are tabulated. When the mean compositions are plotted in the triangular diagram, two fairly tight clusters, one representing "7-dominant" type and the other "7-10-14-even" type, can be clearly distinguished. The "14-dominant" type does not form a tight cluster as such, but its separation from the other two clusters is clear.

Table 4 Means and Standard Deviations for 7Å, 10Å, and 14Å Mineral Contents by Countries (in %)

Country	No. of Samples	7 Å Mineral		10 Å Mineral		14 Å Mineral	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
Bangladesh	53	34.3	10.7	29.2	14.4	36.5	13.6
Burma	16	38.8	13.1	26.6	7.9	34.7	12.4
Cambodia	16	60.6	19.2	4.1	8.5	35.3	17.8
India	73	34.7	16.4	23.7	8.2	41.5	20.6
Indonesia	44	46.6	29.7	0.7	15.3	52.7	30.5
Malaysia	41	59.4	22.2	9.0	2.6	31.6	23.4
Philippines	54	31.2	19.4	2.6	4.5	66.2	24.3
Sri Lanka	33	64.2	25.6	9.1	11.5	26.7	23.6
Thailand	80	59.2	16.5	12.9	12.0	27.9	15.5
Tropical Asia	410	46.4	23.3	13.9	14.4	39.7	23.8

Among the figures of standard deviation, the ones for 7 Å mineral content of Thai soils and for 10 Å mineral content of Bangladesh soils are remarkably low relative to their high means. Thus, a high kaolin content and a high illite content can be regarded as characteristic mineralogical features of Thai soils and Bangladesh soils, respectively. Very low illite (10 Å mineral) contents for Cambodia, Indonesia, and Philippine soils are also noteworthy.

3. Total Chemical Composition

The mean total chemical composition of the samples from the respective countries are shown in Table 5. It is clear from the table that soils from Indonesia and the Philippines

Table 5 Mean Total Chemical Composition by Countries (in %)

Country	No. of Samples	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	MnO_2	TiO_2	K_2O	P_2O_5
Bangladesh	53	70.85	5.74	16.92	1.01	1.18	0.08	1.01	3.09	0.12
Burma	16	69.48	5.68	18.26	1.57	0.92	0.08	0.87	3.01	0.13
Cambodia	16	81.13	4.61	11.52	0.27	0.40	0.09	1.21	0.68	0.09
India	73	71.25	6.94	14.58	1.91	1.20	0.13	1.32	2.55	0.12
Indonesia	44	60.10	10.34	22.86	3.00	1.22	0.25	1.33	0.72	0.18
Malaysia	41	74.22	2.97	18.94	0.14	0.51	0.03	1.03	2.02	0.14
Philippines	54	66.19	7.73	19.57	2.83	1.26	0.23	1.03	0.99	0.17
Sri Lanka	33	76.45	5.35	12.98	1.00	0.66	0.10	1.50	1.82	0.14
Thailand	80	80.41	3.60	12.46	0.43	0.52	0.08	0.99	1.42	0.09
Tropical Asia	410	72.16 (11.51)	5.94 (3.73)	16.34 (6.98)	1.42 (1.96)	0.92 (0.76)	0.12 (0.12)	1.14 (0.60)	1.83 (1.27)	0.13 (0.08)
Japan	155	71.77 (4.89)	6.00 (2.82)	16.26 (2.04)	1.86 (1.16)	0.75 (0.46)	0.13 (0.06)	0.88 (0.34)	2.14 (0.74)	0.22 (0.10)

Figures in parentheses are standard deviations.

have similar total chemical compositions, i.e., low silica content and high iron oxide, alumina and manganese oxide contents. They are generally rich in alkaline earth bases and phosphorus, but poor in potash. In short, they have all the characteristics of materials weathered from basic volcanic rocks.

Soils from Cambodia and Thailand seem to have many characteristics in common; silica content is very high, while the values for iron, aluminum, manganese, alkaline earths, and phosphorus contents are among the lowest. They seem to be on the opposite extremity from the soils of Indonesia and the Philippines. Only in potash content there is an appreciable difference between these two countries. A higher potash content of Thai soils may be ascribed to the presence of deltaic soils, which have higher amounts of clay as well as potash-bearing 10 Å minerals and have also been affected by marine and brackish environments.

Malayan soils are as poor in bases and manganese oxide as the soils from Cambodia and Thailand. The low pH, as stated in the preceding paper[1)], of the soils from these countries is definitely related to the low total base contents. The main difference between Malayan soils and Cambodian and Thai soils is that the former has lower silica and higher alumina contents. This reflects the clayey texture of Malayan soils. Another peculiar feature of Malayan soils is the extraordinarily low iron content in spite of the high clay content. This could be explained by the granitic nature of the parent materials. The high potash content may be due to the same cause. The relatively high phosphorus content of Malayan soils is due to common occurrence of swampy soils that often accumulate phosphorus by certain biological mechanisms.

Sri Lanka soils are also highly siliceous and low in iron oxide and alumina, reflecting their sandy texture. The alkaline earths and manganese contents are moderate, probably due to the less depleted Dry Zone soils. Relatively high potash, phosphorus oxide and titanium oxide contents are related to the residual nature of the parent material weathered from gneissic rocks.

Soils from Bangladesh, Burma and India seem to make up another group. Contents of all the elements except potash are medium and deviate by narrow margins from the overall means. The only peculiar feature is their high potash content which incidentally coincides well with the particularly high 10 Å mineral contents of these three countries (24–29%).

If we compare the overall mean composition for the tropical Asian paddy soils with the mean total composition for the same 155 Japanese paddy soils as cited above, the similarity in the contents of the three macro-elements, i.e., SiO_2, Fe_2O_3, Al_2O_3, is very striking. A difference between the two groups, however, can be noted in the figures of standard deviation. As readily understood from the fact that latosols or such strongly weathered sandy soils as found in the Khorat Plateau region of Thailand are absent, Japanese soils are much more homogeneous and the standard deviation, therefore, is much smaller.

Among the rest of the elements, CaO, TiO_2, and P_2O_5 show slight difference in their contents between the two groups. Though these differences are not statistically significant, they may warrant some remarks. Quite unexpectedly, in spite of stronger acidity the mean CaO content is higher for Japanese soils. The greater part of the CaO must be present in unweathered primary minerals. The higher TiO_2 content in tropical Asian soils is a reflection of the more intensive weathering, causing residual accumulation of such titanium bearing minerals resistant to weathering as rutile and anatase. The difference in phosphorus content is most remarkable. As stated in the preceding paper[1)], phosphorus is so readily fixed by iron and aluminum that its content in the soil is modified rather easily by fertilizer application. The higher phosphorus content in Japanese soils is, thus, most probably due to this reason.

For each of the elements a brief note is given by referring to a 10-class histogram prepared in the same manner as in the preceding paper.[1)]

a) SiO_2 (cf., Fig. 5)

The histogram shows, besides the mode at class 4 or silica content of 65–70%, a small peak at class 10 corresponding to silica content of 95–100%. If we count the number of highly siliceous samples falling into classes 9 and 10 (SiO_2 content$>$90%), the following table is obtained:

Bangladesh	2	Malaysia	2
Burma	0	Philippines	0
Cambodia	6	Sri Lanka	4
India	2	Thailand	25
Indonesia	1	Sum	42

Most of the highly siliceous samples come from either Thailand or Cambodia. They are derived from similar geologic formations (Mesozoic sandstones) distributed widely from the Khorat Plateau of Thailand to Cambodia. Highly weathered soils developed on laterite-bearing high terraces and plateaus are also sandy and siliceous and are included in the above table.

Soils containing less than 55% SiO_2 (class 1) are mostly latosols from Indonesia which have high contents of iron oxide and alumina and low contents of alkaline earths. But a few soils from Indonesia that are made up of unweathered volcanic sands also fall into this class. Thus, the class 1 samples consist of two very contrasting groups of soils, one, the majority group, of strongly weathered clayey soils of latosol type and the other of relatively unweathered highly potential soils.

b) Fe_2O_3 (cf., Fig. 6)

The least siliceous latosolic soils, as mentioned in the preceding paragraph, fall into the most iron-rich classes of the histogram (classes 8, 9, and 10), while the most siliceous ones come into class 1. Thus, silica and iron oxide contents are highly negatively correlated.

Malayan soils have a very low mean iron content. Their distribution among different classes of the histogram is as follows; 9 in class 1, 22 in class 2, 7 in class 3, and 3 in class 4. None of the samples contain more than 8% of Fe_2O_3.

c) Al_2O_3 (cf., Fig. 7)

Unlike the other elements, the histogram for alumina is apparently negatively skewed, having the mode at class 7 that corresponds to Al_2O_3 content of 18–21% and the overall mean at 16.3%. Again, alumina and silica contents are conversely correlated. Even the

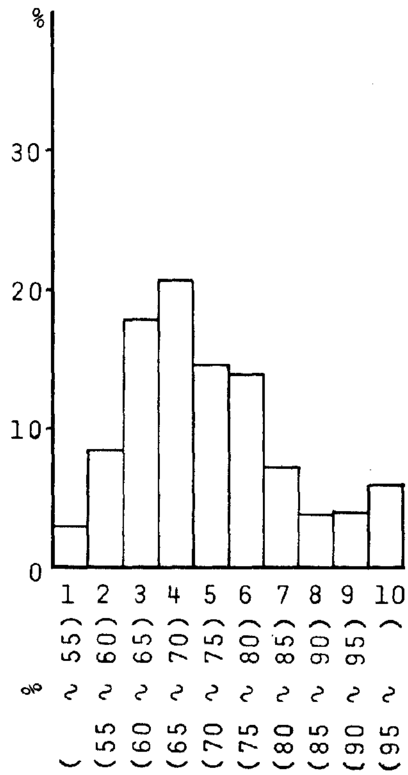


Fig. 5 Histogram for total silica of paddy soils in tropical Asia

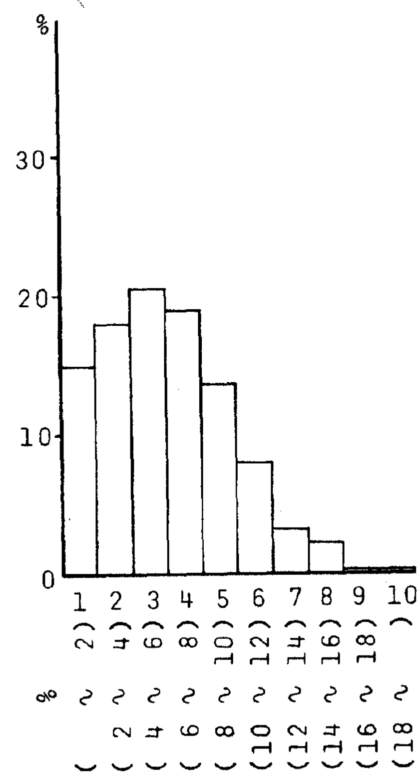


Fig. 6 Histogram for total iron oxide of paddy soils in tropical Asia

pattern of the histogram for alumina is just like a reversal of that for silica. A small peak at class 1 is mostly due to the very highly siliceous samples containing>95% of silica and the samples falling into class 10 are the same latosols as referred to under silica.

d) CaO (cf., Fig. 8)

The histogram is strongly positively skewed. Forty percent of the total samples fall into class 1 or have CaO contents of less than 0.5%. As stated earlier, Cambodia, Malaysia, and Thailand samples are poorest in alkaline earth elements. The distribution of the samples from these three countries among different classes of the histogram is as follows:

Class	1	2	3	4–10
Cambodia	13	2	1	0
Malaysia	40	1	0	0
Thailand	56	22	0	2

On the contrary, the number of samples from each country falling into class 10 (CaO content>4.5%) are as follows; 2 from Burma, 4 from India, 9 from Indonesia, 6 from the Philippines, and 1 from Sri Lanka. They are soils derived either from relatively unweathered basic volcanic sands (Indonesia, Philippines, and Sri Lanka) or from calcareous sediments (Burma and India), some of which are grumusolic.

e) MgO (cf., Fig. 9)

Generally, magnesium behaves similarly to calcium, both being the constituents of

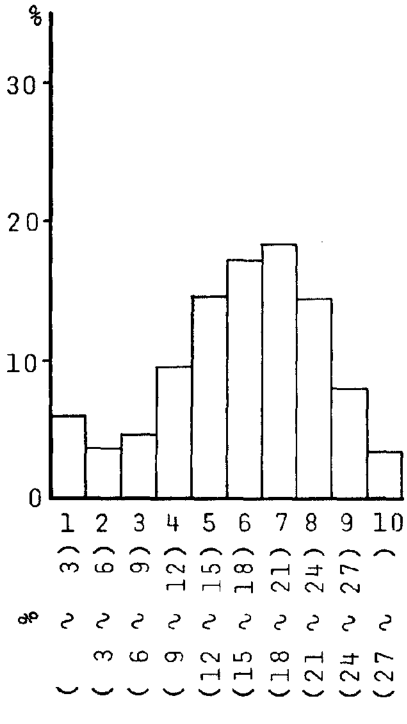


Fig. 7 Histogram for total alumina of paddy soils in tropical Asia

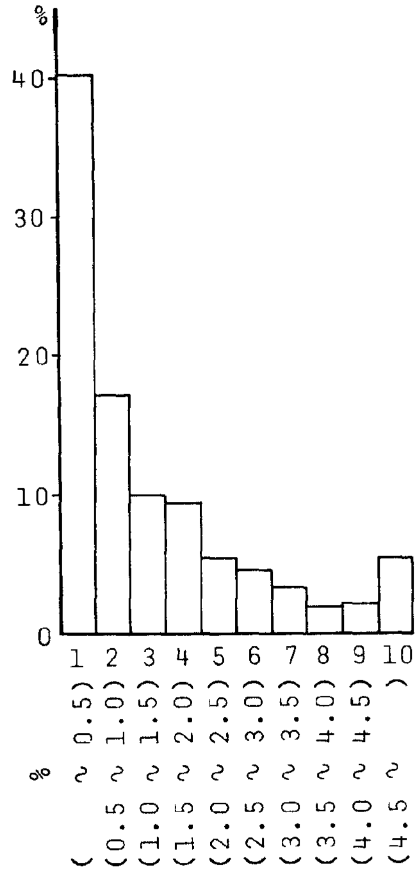


Fig. 8 Histogram for total calcium oxide of paddy soils in tropical Asia

basic primary minerals. There is, however, an important difference in that magnesium is present in such 14 Å clay minerals as montmorillonite and vermiculite as one of the constituent elements while calcium is not. Thus, the soils containing an appreciable amount of 14 Å minerals usually have 1% or more magnesium. But in these soils having 7 Å minerals as the dominant clay species, there is no mechanism to retain magnesium and its content drops to a very low level. A shallow minimum at class 2 of the histogram may be due to this effect.

Very high MgO contents (say$>$2%) are found in soils containing high amounts of CaO or in those recently reclaimed from marine clays.

f) MnO_2 (cf., Fig. 10)

Manganese is a mobile element especially in paddy soils, as it is easily reduced to acquire a high solubility. General resemblance of the histograms for MnO_2 and CaO may be related to the similarity in their behavior in paddy soils.

High contents of manganese are seen for the soils derived from basic volcanic ejecta in the Philippines and Indonesia. Manganese contents of Malayan soils are exceptionally low. Thirty-seven out of 41 sample soils fall into class 1 and the maximum content is only 0.11%, which is even below the overall mean for the entire samples from tropical Asia. As

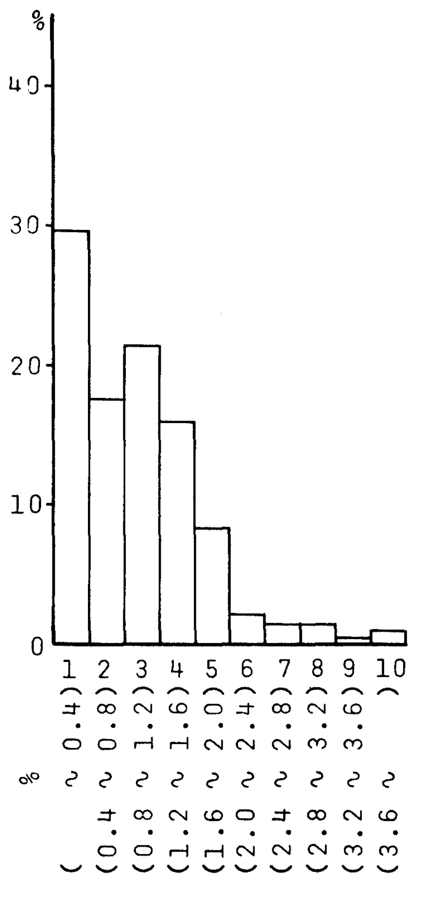


Fig. 9 Histogram for total magnesium oxide of paddy soils in tropical Asia

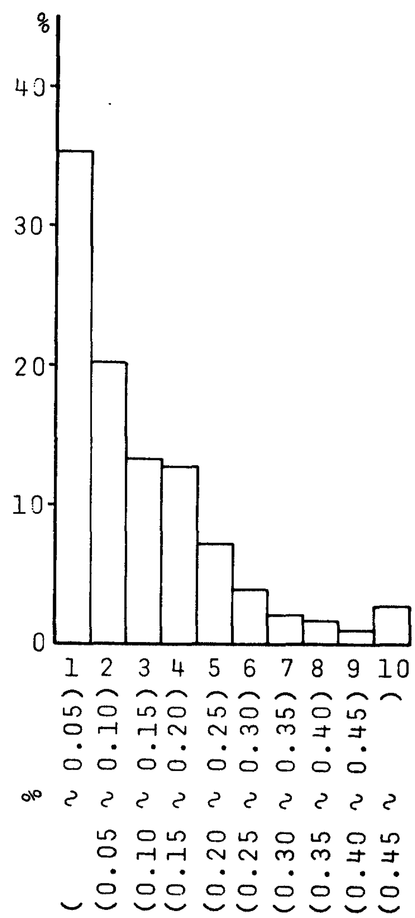


Fig. 10 Histogram for total manganese oxide of paddy soils in tropical Asia

in the case of iron, the paucity of manganese in the granitic parent materials is probably the primary cause of this.

g) TiO_2 (cf., Fig. 11)

Titanium is one of the most immobile elements found in the soil. It usually occurs as independent minerals, such as rutile and anatase, which are extremely resistant to weathering. Therefore, its content in the soil is primarily governed by that in the parent materials.

The histogram shows a very high concentration of samples at class 4 that corresponds to TiO_2 content of 0.9–1.2%. One Thai soil and one Indonesian soil show exceptionally high TiO_2 contents, 7.3 and 6.1%, respectively. It is difficult to give a plausible explanation for this.

h) K_2O (cf., Fig. 12)

Potassium is contained not only in such primary minerals as micas and orthoclase feldspars, but also, like magnesium, in secondary clay minerals. The 10 Å minerals contain about 10% of potash in its interlayer space. As these potash-containing minerals

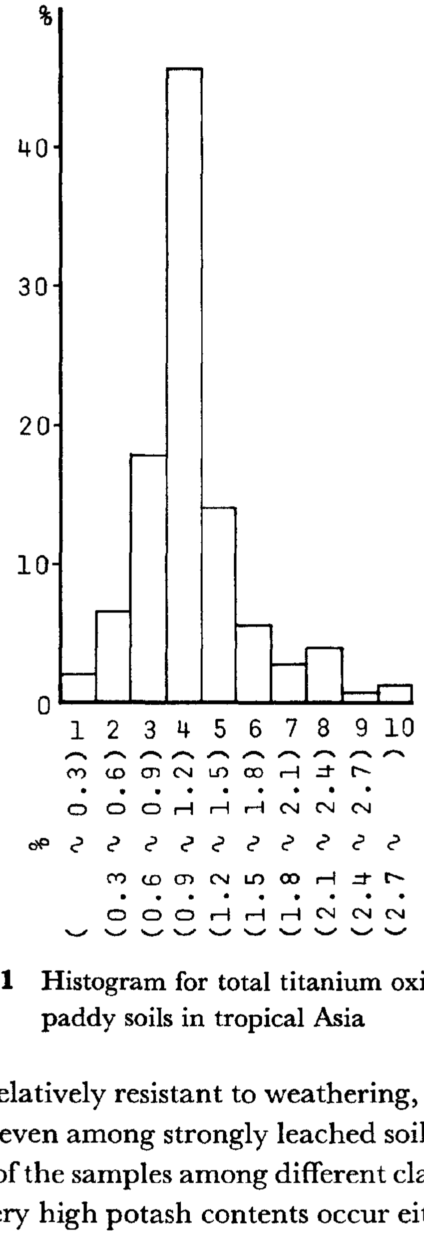


Fig. 11 Histogram for total titanium oxide of paddy soils in tropical Asia

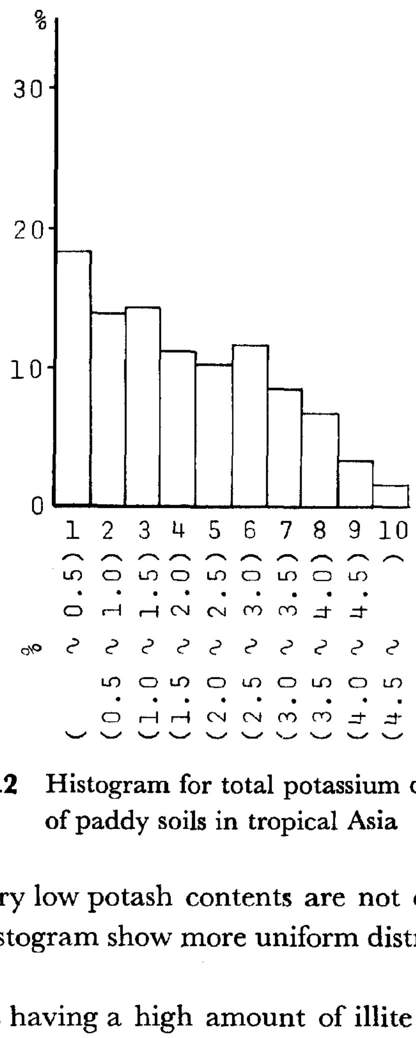


Fig. 12 Histogram for total potassium oxide of paddy soils in tropical Asia

are relatively resistant to weathering, soils having very low potash contents are not common even among strongly leached soils. Thus, the histogram show more uniform distribution of the samples among different classes.

Very high potash contents occur either in the soils having a high amount of illite (e.g. Bangladesh soils), or in relatively unweathered sandy soils derived from granitic or gneissic rocks (e.g., Malaysia and Sri Lanka soils). Samples poor in potash are most common among strongly weathered sandy soils from Cambodia and the Khorat Plateau region of Thailand, and also among the soils derived from basic volcanic ejecta, potash content of which is originally low.

i) P_2O_5 (cf., Fig. 13)

The total phosphorus content determined by X-ray fluorescence method in this study is higher than that determined by chemical digestion method as reported in the preceding paper.[1] The reason for this may be sought in the incompleteness of dissolution of phosphorus in the chemical method, and to some extent in the recalculation of the element contents by neglecting Na and other minor elements.

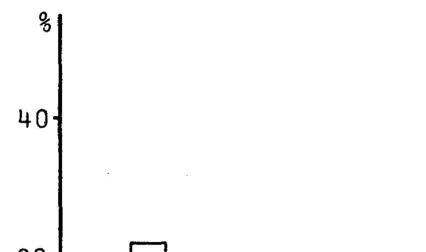


Fig. 13 Histogram for total phosphorus oxide of paddy soils in tropical Asia

The general pattern of the histogram, however, is similar to the previous one, having the mode at class 3 and a small maximum at class 10. Many of the samples falling into class 10 are soils on unweathered volcanic sands from the Philippines and an ando soil and some latosols from Indonesia. Soils very poor in phosphorus are concentrated in the Khorat Plateau region of Thailand.

Summary

The material characteristics of 410 sample soils from tropical Asian countries have been described in terms of texture, clay mineralogy, and total chemical composition.

Paddy soils of Indonesia, Malaysia, and the Philippines are generally heavy-textured, while those of Sri Lanka are sandy and poor in silt. Bangladesh soils are characterized by a high content of silt. Soils from Burma, Cambodia, India, and Thailand are more heterogeneous with respect to textural composition.

There seems to be a general parallelism between clay mineral composition and total chemical composition and in terms of these two material characteristics the following three

groups may be set up:

7 Å mineral dominant, high silica and low bases—Cambodia, Malaysia, Sri Lanka and Thailand,

14 Å mineral dominant, low silica and high bases—Indonesia and the Philippines,

7-10-14 Å minerals evenly contained, medium chemical composition—Bangladesh, Burma, and India.

As the material characteristics are correlated with each other, separate discussions on individual items seem to be insufficient. In one of the papers to follow we will deal with these material characteristics collectively in order to set up a system for classification of paddy soil materials in tropical Asia.

References

1) Kawaguchi, K. and Kyuma, K., "Paddy Soils in Tropical Asia, Part 1. Description of Fertility Characteristics," *Tonan Ajia Kenkyu*, Vol. 12, No. 1, pp. 3–24 (1974)

2) Kitagawa, Y., Kyuma, K. and Kawaguchi, K., "Clay Mineral Composition of Some Volcanogenous Soils in Indonesia and the Philippines," *Soil Sci. & Plant Nutr.*, Vol. 19, No. 3, pp. 147–159 (1973)

3) Norrish, K. and Chappel, B. W., X-ray Fluorescence Spectrography. In Zussman, J. ed. *Physical Method in Determinative Mineralogy*, Academic Press, N.Y., 1967

4) Kyuma, K., Okagawa, N. and Kawaguchi, K., "A Numerical Approach to the Classification of Alluvial Soil Materials", *Trans. 10th Int. Congr. Soil Sci., Moscow*, Vol. VI, pp. 543–551 (1974)

5) Soil Survey Staff, *Soil Survey Manual*, USDA Handbook 18, 1951.